THE USE OF ENDOPEROXIDES FOR THE TREATMENT OF INFECTIONS CAUSED BY FLAVIVIRIDAE, INCLUDING HEPATITIS C, BOVINE VIRAL DIARRHEA AND CLASSICAL SWINE FEVER VIRUS

Background of the Invention

5 The invention relates generally to the use of sesquiterpene lactones in the treatment of infections caused by *Flaviviridae* and, more specifically, to the use of sesquiterpene lactone endoperoxides to treat hepatitis C infections, yellow fever, dengue fever, bovine viral diarrhea and classical swine fever.

Chronic hepatitis C infection is a substantial public health problem affecting 180 million
10 people worldwide (3% of the population), including 4 million people in the United States and is a leading cause of chronic liver disease. It is predicted that HCV infection will continue to rise in the U.S. with three times as many people infected by the year 2010. Infection with the hepatitis C virus may lead to an increased probability of developing serious and, in some cases, life threatening chronic liver disease including liver failure and cancer.

15 Chronic liver disease is the tenth leading cause of death among adults in the United States, and accounts for approximately 25,000 deaths annually, or approximately 1% of all deaths. Population-based studies indicate that 40% of chronic liver disease is HCV-related, resulting in an estimated 8,000–10,000 deaths each year. Current estimates of medical and work-loss costs of HCV-related acute and chronic liver disease are greater than $600 million annually,
20 and HCV- associated end-stage liver disease is the most frequent indication for liver transplantation among adults. Because most HCV-infected persons are aged 30–49 years, the number of deaths attributable to HCV- related chronic liver disease could increase substantially during the next 10–20 years as this group of infected people reaches ages at which complications from chronic liver disease typically occur.

25 HCV is transmitted primarily through large or repeated direct percutaneous exposures to blood. In the United States, the two most common exposures associated with transmission of HCV are blood transfusion and injecting-drug use. Therapy for hepatitis C is a rapidly changing area of clinical practice. Combination therapy with interferon and ribavirin, a nucleoside analogue, is approved for the naive treatment of patients with chronic hepatitis C. Studies of
30 patients treated with a combination of ribavirin and interferon have demonstrated a substantial

increase in sustained response rates, reaching 40%-50%, compared with response rates of 15%-25% with interferon alone. Most patients receiving interferon experience flu-like symptoms early in the treatment, but these symptoms diminish with continued treatment. Later side effects include fatigue, bone marrow suppression and neuropsychiatric effects (e.g. apathy, cognitive

5 changes, irritability and depression). Interferon dosage must be reduced in 10%-40% of patients and discontinued in 5%-15% because of severe side effects. Ribavirin can induce hemolytic anemia and can be problematic for patients with pre-existing anemia, bone marrow suppression or renal failure. In these patients, combination therapy should be avoided or attempts should be made to correct the anemia. Hemolytic anemia caused by ribavirin also can be life-threatening

10 for patients with ischemic heart disease or cerebral vascular disease. Ribavirin is teratogenic, and female patients should avoid becoming pregnant during therapy. Other treatments, including corticosteroids, ursodiol and thymosin, have not been effective. High iron levels in the liver might reduce the efficacy of interferon. Use of iron reduction therapy (phlebotomy or chelation) in combination with interferon has been studied, but results have been inconclusive

15 (www.cdc.gov). Therefore, a strong medical need exists to discover and develop new bioactive molecules that can be used to treat hepatitis C infections with fewer or reduced side effects and better efficiency compared to the current available treatments.

Summary of the Invention

20 It has been discovered that sesquiterpene lactones having the generic formula:
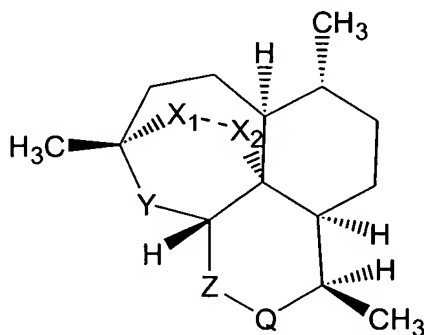
have activity against infections caused by *Flaviviridae*, including hepatitis C, bovine viral diarrhea, and classical swing fever viruses. Representative, presently preferred sesquiterpene

lactones are described in this application, although it will be apparent to those skilled in the art

that other sesquiterpene lactone compounds will be useful in the treatment of infections caused

by *Flaviviridae*. Also included are pharmaceutically acceptable salts of these compounds.

Preferred sesquiterpene lactones are the sesquiterpene lactone endoperoxides artemisinin,

5   dihydroartemisinin, artensunate, and artemether.

## Brief Description of the Drawings

Fig 1 is an illustration of the chemical structure of artemisinin, dihydroartemisinin,

artemether and artesunate.

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Detailed Description of Preferred Embodiments

Here we describe the antiviral effect of sesquiterpene lactones, and preferentially

sesquiterpene lactone endoperoxides, such as artemisinin, dihydroartemisinin, artemether and

artesunate, against specific *Flaviviridae* such as the hepatitis C virus.

15   Preferred sesquiterpene compounds of the present comprise compounds of the formula:
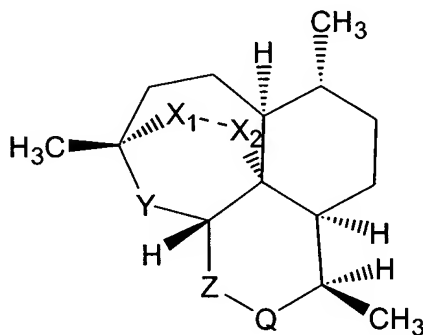
wherein: X_1 and X_2 are selected from O, S, Se and NH; Y is selected from O, S, Se, and NH; Z is

selected from O, NH, S, and Se, and Q is selected from CO, CHOH, CHOCH$_3$, CHOC$_2$H$_5$,

20   CHOC$_3$H$_7$, and CHOCOCCH$_2$CH$_2$COOH, and the pharmaceutically acceptable salts thereof.

The presently particularly preferred sesquiterpene compounds of the invention include

artemisinin, wherein X_1 and X_2 are O, Y is O, Z is O and Q is C=O; dihydroartemisinin

(artemisinin except Q is CHOH), artemether (artemisinin except Q is CHOCH$_3$); arteether

(artemisinin except Q is COC$_2$H$_5$); a propyl product (artemisinin except Q is CHOC$_3$H$_7$); and

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artesunate (artemisinin except Q is CHOCOCH$_2$CH$_2$COOH). The presently most particularly preferred sesquiterpene compound of the invention is dihydroartemisinin.

Endoperoxides have a peroxo linkage (-O-O-) that in these products is believed to be important to its activity as an antimalarial. Substitution of the peroxo linkage with a -S-S- (disulfide) or -Se-Se-(diselenide) or -N-O- or -NH-NH-(hydrazines) and the various combinations of these linkages will create novel compounds that also may have activity.

The *Flaviviridae* is an important family of human and animal RNA viral pathogens (Rice CM. 1996. *Flaviviridae: the viruses and their replication*. In: Fields BN, Knipe DM, Howley PM, eds. Fields virology. Philadelphia: Lippincott-Raven Publishers. Pp 931-960). The three currently recognised genera of the *Flaviviridae* exhibit distinct differences in transmission, host range and pathogenesis. Members of this classical flavivirus are the yellow fever virus, dengue virus and the pestiviruses, such as bovine viral diarrhea virus (BVDV) and the classical swine fever virus (CSFV). The most recently characterised member of this family is the common and exclusively human pathogen, hepatitis C virus (HCV). *Flaviviridae* are single strand RNA viruses having (+) sense RNA genome polarity. Other virus families with (+) sense RNA include the *Picornaviridae, Togaviridae, Caliciviridae* and the *Coronaviridae*.

The inventive compounds may be used in their native form or as salts. In cases where compounds are sufficiently basic or acidic to form stable nontoxic acid or base salts, administration of the compounds as salts may be appropriate. Examples of pharmaceutically acceptable salts are organic acid addition salts formed with acids which form a physiological acceptable anion, for example, acetate ascorbate, benzoate, citrate, etoglutarate, glycerophosphate, malonate, methanesulfonate, succinate, and tartarate. Suitable inorganic salts may also be formed, including bicarbonate, carbonate, hydrochloride, nitrate, and sulfate, salts.

Compounds of the present invention can conveniently be administered in a pharmaceutical composition containing the compound in combination with a suitable excipient, the composition being useful in combating viral infections. Depending on whether the preparation is used to treat internal or external viral infections, the compounds and compositions of the present invention can be administered parenterally, topically, intravaginally, orally, or rectally.

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For parenteral administration, solutions of the active compound or its salts can be prepared in water, optionally mixed with a nontoxic surfactant. Dispersions can also be prepared in glycerol, liquid polyethylene glycols, triacetin, and mixtures thereof and in oils.

Useful dosages of the compound can be determined by comparing their in vitro activity.

5   Methods for the extrapolation of effective dosages to humans are known to the art.

The compound is conveniently administered in unit dosage form; for example, containing 0.1 to 2000 mg, conveniently 100 to 1000 mg, most conveniently, 100 to 500 mg of active ingredient per unit dosage form. The desired dose may conveniently be presented in a single dose or as divided doses administered at appropriate intervals, for example, as two, three, four or more

10   sub-doses per day. The sub-dose itself may be further divided, e.g., into a number of discrete loosely spaced administrations; such as multiple inhalations from an insufflator or by application of a plurality of drops into the eye.

For internal infections, the compositions can be administered orally or parenterally at dose levels, calculated as the free base, of about 1 to 30 mg/kg, preferably 1 to 10 mg/kg of

15   mammal body weight.

The exact regimen for administration of the compound and compositions disclosed herein will necessarily be dependent upon the needs of the individual subject being treated, the type of treatment and, of course, the judgment of the attending practitioner. The compounds of the present invention can be administered to an animal in need of treatment. In most instances, this

20   will be a human being, but the treatment of livestock and companion animals is also specifically contemplated as falling within the scope of the instant invention.

Methods and Materials

Artemisinin was purchased from Aldrich. The crude plant extracts of wormwood

25   (*Artemisia absinthum*) KE-4, sweet wormwood (*Artemisia annua*) KE-5, and tarragon (*Artemisia dracunculus*) KE-6, were obtained from Kemin Industries Inc., Des Moines, US. To prepare the KE-4, -5, and.–6 samples, 2 g of dried and grinded wormwood, sweet wormwood or tarragon, respectively, was stirred for 8 hours at room temperature with 200 ml of hexane p.a. Afterwards, the suspension was filtered through a G3 glass filter and evaporated under reduced pressure. The

30   remaining dark residue was used for the biological screenings. Artemether, dihydroartemisinin

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and artesunate were purchased from Dafra Pharma. The compounds were screened against various pathogenic viruses such as the human immunodeficiency virus (HIV), herpes simplex virus (HSV), vaccinia virus (VV), the varicella zoster virus (VZV) and the human cytomegalovirus (CMV). For all viruses, except for CMV, the EC_{50} (effective compound

5 concentration required to inhibit HIV-induced cytopathicity in human CEM cell cultures, HSV- and VV-induced cytopathicity in human embryo fibroblast E_6SM cell cultures, and VZV-induced plaque formation in human embryonic lung (HEL) cell cultures by 50%.) was determined. For determination of antiviral activity, expressed in IC_{50}, against CMV, human embryonic lung fibroblast (HEL) cells grown in 96-well microplates were infected with 20 PFU virus/well.

10   After 2 hours of incubation at 37°C, the infected cells were replenished with 0.1 ml of medium containing serial dilutions of the test compound. On day 7 the plaques were counted microscopically after staining the cells with Giemsa's solution. The minimum antiviral concentration was expressed as the dose required to inhibit virus-induced plaque formation by 50%.

15   The compounds were also screened against *Flavivirida*. Due to the fact that there is no adequate *in vitro* analysis to screen against HCV, it was decided to screen against the bovine viral diarrhea virus (BVDV), as it shares many similarities with the hepatitis C virus (Frolov I, McBride S and Rice CM. Cis-acting RNA elements required for replication of bovine.viral diarrhea virus-hepatitis C virus 5' non-translated region chimeras. RNA 4, 1418-1435 (1998)).

20 Further screenings of artemether against different strains of BVDV have been carried out.

        The compounds were also checked for anti-tumor activity via the proliferation of murine leukemia cells (L1210/0), murine mammary carcinoma cells (FM3A) and human T-lymphocyte cells (Molt4/C8, CEM/0). The best antiviral activity observed against CMV and VZV was from KE 6. To a lesser extent, artemisinin showed antiviral activity against HSV-2 and VV.

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Results and Discussion

        In a first set of screenings (Table 1), the anti-viral activity of artemisinin and some crude *Artemisia* extracts (KE-4, KE-5 and KE-6) was checked against HIV-1, HIV-2, HSV-1, HSV-2, VV, CMV and VZV.

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Table 1 - Results of screenings against HIV-1, HIV-2, HSV-1, HSV-2, VV, CMV and VZV

Compound	[a]EC50 (µg/ml)								
	HIV-1 (IIIB) (CEM)	HIV-2 (ROD) (CEM)	HSV-1 (KOS) (E6SM)	HSV-2 (G) (E6SM)	VV (E6SM)	CMV Davis (HEL)	CMV AD-169 (HEL)	VZV (HEL) OKA	VZV (HEL) YS
Artemisinin	> 20	>20	> 400	240	240	> 50	> 50	> 50	> 50
KE-4	> 20	>20	> 80	> 80	> 80	> 50	> 50	> 50	> 50
KE-5	> 100	> 100	> 240	> 80	> 80	> 50	> 50	> 50	> 50
KE-6	> 20	> 20	> 80	> 80	> 80	10	33	17	30

[a]50% Effective concentration or compound concentration required to inhibit HIV-induced cytopathicity in human lymphocyte CEM cell cultures, HSV- and VV-induced cytopathicity in human embryo fibroblast E_6SM cell cultures, and CMV- and VZV-induced plaque formation in human embryonic lung HEL cell cultures by 50%.

A second anti-viral screening (Table 2) was performed in order to check the activity against bovine viral diarrhoea virus (BVDV - strain Pe515) in bovine kidney (MDBK) cells.

Table 2 - Results of screenings against BVDV in MDBK cells

Compound	EC_{50} (µg/ml) BVDV	MTC (µg/ml) MDBK
Artensunate	0.07	0.4
Artemether	0.3	> 100
Artemisinin	0.4	>100
Dihydroartemisinin	0.05	0.4
KE 4	>100	>100
KE 5	>100	>100
KE 6	>100	100

Antiviral activity was assessed using the Pe515 strain of BVDV on MDBK cells. Both antiviral activity and cytotoxicity was determined by means of the MTS method. The EC_{50} is the concentration required to reduce virus induced cytopathic effect by 50%. The MTC (minimal toxic concentration) was defined as the concentration that caused >=20% reduction in cell metabolism.

The MTC was not reached at the highest concentration (100 µg/ml) for MDBK cells when treated with artemether, artemisinin, KE 4 and KE5. In this test a strong activity of the

endoperoxides artemisinin, dihydroartemisinin, artemether, and artesunate against BVDV, a *Flaviviridae*, was observed while the cell toxicity stayed low. Therefore, these products could be positioned as a possible treatment for infections caused by *Flaviviridae*.

Artemether was screened against different BVDV strains, as well as against BDV (border disease virus)(Table 3).

Table 3 - Results of screening of artemether against BVDV and BDV

Artemether	100 μg/ml	20 μg/ml	4 μg/ml	800 ng/ml	160 ng/ml	32 ng/ml	6.4 ng/ml	1.28 ng/ml	0.512 ng/ml	0.256 ng/ml
Non infected	Toxic	-	-	-	-	-	-	-	-	-
BVDV II ncp	Toxic	++	++	++	+++	+++	+++	+++	+++	+++
BVDV I cp	Toxic	+	+	+	+	++	++	++	++	++
BVDV I ncp	Toxic	+	+	+	++	+++	+++	+++	+++	+++
BDV	Toxic	+	+	+	++	++	++	++	++	++

+++   All cells are positive
++   +/- 50% of the cells are positive
+   +/- 10 % of the cells are positive

BVDV Bovine viral diarrhea virus
BDV   Border disease virus
cp   Cytopathogen strain
ncp   Non cytopathogen strain

Especially against BVDVI cp, the BVDV strain which resembles HCV most, the effect of artemether can be seen clearly. The product has an EC_{90} = 0.16 μg/ml. The toxic concentration in these experiments was found to be around 100 μg/ml. Also against BDV, an effect could be observed (EC_{90} = 0.8 μg/ml).

Artemisinin and the crude *Artemisia* extracts (KE-4, KE-5 and KE-6) were screened against the tumor cell lines L1210/0, FM3A/0, Molt4/C8 and CEM/0, but no interesting activity could be found.

Conclusion

In the first screenings against DNA-viruses and retroviruses we could not notice any significant antiviral activity. In the second screenings against the BVDV (RNA virus) we clearly indicated strong anti-viral activity of artemisinin, artesunate, artemether, and dihydroartemisinin.

5 These products, all endoperoxides, showed significant better activity against BVDV, compared to the tested crude Artemisia extracts. Since BVDV and HCV have many similarities, artemisinin, artemether, artesunate, dihydroartemisinin and probably other peroxides may have strong and selective antiviral properties against HCV.

Although the invention has been described with respect to a preferred embodiment

10 thereof, it is to be also understood that it is not to be so limited since changes and modifications can be made therein which are within the full intended scope of this invention as defined by the appended claims.